

MINING HAUL TRUCK CAB NOISE: AN EVALUATION OF THREE ACOUSTICAL ENVIRONMENTS

S. B. Bealko, NIOSH, Pittsburgh, PA

Abstract

Mining haul trucks comprise the majority of the equipment used in underground limestone mining operations and are known to emit high levels of noise. A previous study conducted by the National Institute for Occupational Safety and Health (NIOSH) indicates that 70-90 percent of all miners have a noise-induced hearing loss (NIHL) great enough to be classified as a hearing disability by retirement age. These results demonstrate the public health need to protect the hearing of workers in the mining industry, including haul truck drivers.

Cab enclosures present an opportunity to isolate the haul truck operator from both truck and other noise in the mining environment. A total of twenty-five haul truck cabs were studied which were divided into three style (treatment) categories determined by soundproofing features and technology for noise reduction: old-, new-, and retrofitted-style. This study examines the contribution of cab acoustics, operator performance, and maintenance to noise reduction for each cab style. Dosimeters were used to measure 8-hr time weighted average sound pressure levels (TWA₈ SPLs) inside and outside the cabs to determine if different acoustical treatments affect cab attenuation. Adherence to the Mine Safety and Health Administration (MSHA) Permissible Exposure Limit (PEL) of 90 dB TWA₈ (with a 90 dB threshold) was used as the main indicator of overall noise reduction achieved. Dosimetry results indicate only 2% of the samples exceeded the PEL, but samples could still be reduced much further. Descriptive and comparative statistics indicate that noise levels inside the new-style cabs are significantly lower than the other two cab styles. Also, data suggest that there is no difference in noise exposures when comparing the old-style to retrofitted cab styles. Operator influence (opening doors and windows) was a significant factor for increasing noise exposure.

This paper demonstrates that properly designed cabs can achieve major noise reductions, but noise levels could still be reduced much further below the MSHA PEL. New-style cabs, equipped with modern noise-reduction treatments, exhibit much lower noise exposures than the other two cab styles, and the effectiveness of the current noise-reduction treatments for retrofitted cabs is questionable. Haul truck driver observations indicate that improved noise exposure reduction training is needed. Finally, specific targets for future noise reduction research are suggested that will further contribute to the prevention of hearing loss for haul truck operators.

Introduction

This study investigates haul truck cab noise in underground limestone mines which employ nearly 2000 workers at 117 mines across the United States. In this industry, hazardous noise is present from drilling, blasting, rock crushing operations, and the predominance of large and noisy equipment. Continued exposure of miners to high noise levels can cause damage to the inner ear. This result of this damage is a permanent shift in the hearing threshold, known as a noise-induced hearing loss (NIHL). A NIHL makes it difficult to hear and understand everyday speech and is irreversible.

Of special interest is the haul truck (Figure 1) because it comprises the majority (approximately 30%) of the equipment used in the underground limestone industry. With these trucks and most diesel-powered equipment, the engine is generally a major source of noise. Engine noise may emanate from the exhaust, the intake, and the cooling fan. Other significant noise sources include the transmission, drive train, and hydraulic system.



Figure 1. Haul truck and cab.

Noise from these sources reaches the ear via several paths, both directly, by airborne paths, and indirectly, by reflections from various surfaces. In addition, sound in the form of vibrations may travel along or through structures (Daniel et al., 1981). An approach to eliminate or control noise at its source, engineering controls, is through the use of mufflers, gaskets and control of reflected noise. Another way to lower noise levels is to identify, isolate, and treat the many paths along which noise travels with barriers, absorbers and dampers.

Control of haul truck cab noise is important because haul truck operators spend a majority of their time inside the cab. Most mine policies require haul truck operators to remain inside their cab throughout the entire shift except for restroom use, attendance at safety meetings, during maintenance, and sometimes during lunch breaks. Therefore, it is typical for operators to spend almost the entire shift (8 - 10 hrs) inside the haul truck cab.

According to Daniel et al., "Cab enclosures generally are the most efficient way to prevent the radiation of sound through the cab walls." The effectiveness of noise reduction is greater if the cab is lined with an acoustically absorptive material. Most newer haul truck cabs are manufactured with features that are designed specifically for noise reduction (new-style cabs). These features are typically not found as original components in cabs of older trucks (old-style cabs). Sound-proofing materials may be added to the older cabs to upgrade their noise reduction potential (retrofitted cabs).

This study examines noise exposure inside haul truck cabs experienced during a typical workday with normal operator practices, the effect of noise-reduction features inside the cab, the consequence of disabling noise controls (unnecessary open doors/ windows), and the significance of haul truck and cab maintenance factors. The objectives of this study were to:

- Determine if current haul truck cabs provide enough protection to prevent a noise overexposure (as defined by the MSHA PEL) during normal operations.
- Determine if there is a significant difference in the noise exposure as measured inside the old style, new style and retrofitted cabs.
- Analyze critical factors that contribute to the cab noise protection potential.

- Observe and consider haul truck operator activities (opening of doors or windows) relative to established operating procedures and to determine this effect on the noise exposure inside the cab.
- Suggest specific research areas to further improve noise reduction in haul truck mining cabs.

Federal Regulation of Noise Exposure in Mining

Efforts to combat NIHL in miners began in 1969 with the enactment of the Federal Coal Mine Safety and Health Act (Public Law 91-173). This law set forth requirements for protecting coal miners from among other hazards, exposure to excessive noise. Later, the Federal Mine Safety and Health Act of 1977 (Public Law 95-144) broadened the scope of the law to include noise protection for all miners of all mineral types (the Acts are detailed in 30 CFR, Subchapter O, Part 70, Subpart F, 1997). MSHA was enforced a PEL that was an 8-hour, time-weighted average (TWA₈) of 90 dBA (slow) (with a 90 dB threshold), but a hearing conservation program was not mandated unless a citation was issued for overexposure (Joy and Middendorf, 2007).

On September 13, 2000, there was further progress in controlling mining-related noise when MSHA established the new Health Standards for Occupational Noise Exposure (Federal Register, 1999). This standard adopted a provision similar to Occupational Safety and Health Administration's (OSHA's) Hearing Conservation Amendment (29 CFR 1910.95), where a miner is required to be enrolled in a hearing conservation program (HCP) if the full-shift noise exposure is at or above the action level (AL) of TWA₈ 85 dBA (slow) (80 dBA threshold).

With the PEL remaining the same, other requirements of the new regulations included the primacy of engineering and administrative controls for noise exposure reduction, the implementation of a noise exposure monitoring system, and the relegation of the use of hearing protection to the hearing conservation program. The implementation of these regulations has served to reinforce the importance of noise reduction throughout the mining industry.

Methodology

Categorization of Haul Truck Cabs

Presently, haul truck cabs are manufactured with built-in design features for noise reduction (new-style cabs) whereas cabs on older vehicles lack many such features (old-style cabs). There are also cases where the cab components have worn out before the haul truck is taken out of service. Often, to extend the life of the truck, the original components of these cabs are upgraded with materials (e.g. foam-materials on cab walls or new gaskets around doors and windows) to reduce noise exposures (retrofitted cabs). In order to compare the noise reduction characteristics for each cab style, criteria were established to divide cabs into the three cab styles or treatment groups. A description of each cab style, along with illustrations, follows.

New-Style Cabs: Noise control features for new-style cabs include sound absorption, vibration damping and sound barriers. Sound absorption materials are soft and porous materials (e.g., flexible polyurethane foam) where the amount of sound absorption is directly related to the amount of treated surface area. Vibration damping materials reduce the amount of vibration energy transmitted between surfaces and are constructed of rigid materials. Sound barrier materials combine mass and flexibility to reduce the sound energy passing between the noise source and the controlled area. Sound barriers, combined with sound absorption materials, can be very effective in controlling noise (Mohanty et al., 2000).

Besides new sound-proofing materials and technology, research to reduce structure-borne noise by determining the best placement for sound-absorbing materials in cabs has been conducted. Researchers created and tested cab designs using computer-aided-engineering methods. Some examples of the new-style cab characteristics are shown in Figure 2. This Figure demonstrates full-upholstery cabs that absorb noise and seals, gaskets, and latches that minimize noise leakage and all-around cab vibration.



Figure 2. Examples of New-Style Cab, a) full-upholstery and window seals b) newer gaskets, door handles, and window cranks.



Figure 3. Examples of Old-Style Cab, a) and b) steel interior with older sealants and gaskets, and c) older door handle.

Old-Style Cabs: It is not uncommon to encounter haul trucks that are twenty years old or older still in use at underground limestone mines. Needless to say, these cab enclosures lack some of the new technologies that reduce noise. A typical cab of this type has a hard steel interior that acts as a noise reflecting surface and there is little use of noise reducing materials. Because these cabs experience wear over time, the original components including cab sealants and gaskets may lose their effectiveness and allow noise leakage. In addition, cab integrity may deteriorate and increase cab noise due to the vibration of doors, windows, or latches. Preserving the integrity of these components is crucial for noise reduction and thus requires a proactive maintenance program. Some examples of old-style cab characteristics are shown in Figure 3. This Figure illustrates steel interior cabs with noise reflective surfaces, and older-style latches, gaskets, and seals.

Retrofitted-style Cabs: This style cab has been upgraded with new technology or materials such as floor mats, insulation, special glass, and other methods to reduce noise. The upgrade may be due to original component deterioration or wear from extensive usage. Figure 4 demonstrates an old-style cab that was upgraded with a material approved by MSHA. This foam material shown was engineered for use in high noise environments and meets the MSHA flammability standards (adopted UL 94 HF-1). It is faced with an aluminized polyester material layer that reflects radiant heat. The facing and foam were fused during processing to create a bond that resists delamination. This material is ideal for sound absorption in enclosed equipment, such as compressors, motors, generators, and pumps. (TUFCOTE, 2006) This material is just one example of the many commercially available soundproofing products. There are also products that reduce noise echo, stop vibrations, and lower noise transmission through glass.

Associated Co-Variables

This study was designed to evaluate cab noise exposure levels given the current maintenance condition, in the typical environmental noise surroundings, and with the haul truck operators performing as usual during a typical workday. Therefore, besides noise-reduction

features in cabs, there are other variables that effect sound levels inside the cab. As part of the methodology, two of these variables referred to as co-variables, were monitored closely throughout the survey. These two co-variables are maintenance and operator performance. Other potential co-variables were considered including maintenance down time, extreme weather and road conditions, and shortened work shifts.



Figure 4. Examples of Retrofitted Cab, foam sound-absorbing material with sealants and gaskets around doors and windows.

Maintenance: Although the effect of noise reduction for specific cab components is difficult to identify and measure, it is evident that improper maintenance of haul trucks and cab enclosures can lessen (or degrade) cab attenuation. Also, deteriorated door and window seals should be replaced and holes in the cab frame should be patched because air gaps and holes can also allow noise leakage. Figures 5 shows examples of cab degradation including inadequate sealing around doors, holes in the cab frame, and the deterioration of soundproofing materials on the roof.

Another essential maintenance issue is a functional air conditioning system to sustain a comfortable and healthy work environment. If the system is in disrepair, haul truck operators will, out of necessity, open doors and windows to seek relief from the heat. When this occurs, the haul truck operators circumvent some of the protective cab features and allow outside noise, dust, or other noxious agents to enter the cab.

Operator Influence: Haul truck operators are encouraged to follow safe operating practices. Most procedures require equipment operators to keep their windows and doors closed as much as possible. However, observations of haul truck drivers during operations reveal that some operators don't always adhere to these practices. One reason, which has already been mentioned, is to cope with malfunctioning air conditioning systems. Another reason is the preference for fresh wind and outside air, regardless of a guarantee for a noisier environment. Smoking and chewing tobacco use can also cause operators to frequently open their windows and doors.

Operators are also encouraged to stay inside the cab and away from noisy environments as much as possible and to report any maintenance needs. Adherence to good practices and procedures for equipment operation can help to reduce noise exposures.

Mine Characteristics

Haul truck cab noise was studied at five underground limestone mines. The typical mining sequence for each mine included drilling the face, blasting the rock, and extraction using front-end loaders and haul trucks. The blasted material was transported to the crushing and screening facilities where it was processed into various sized aggregates. One mine had the crushing/screening plant located underground while the other mines had the facilities located outside the mine approximately 100 - 200 yards from the mine portal.

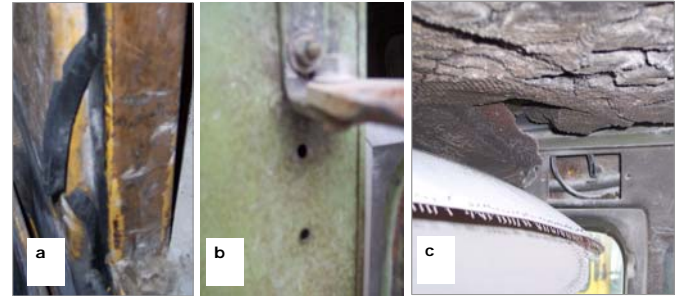


Figure 5. Examples of poor maintenance (a) inadequate sealing around door, (b) hole in cab frame, and (c) deteriorated soundproofing roof materials

Mine production ranged from 1.5 to 2 million tons per year of raw product and employment ranged from 9 to 30 underground employees. Mining heights averaged 22 feet and the mining widths were approximately 40 feet. Most of the underground equipment was diesel-powered with some smaller equipment powered by electricity.

Study Procedure

Several tasks were completed prior to the start of the shift. Twenty-five haul trucks were examined and the cabs were categorized as follows: 5 old-style, 17 new-style, and 3 retrofitted cabs. A pre-shift maintenance inspection of the cab was conducted, including noting the operational condition of the air conditioning unit and any obvious acoustic material maintenance needs.

Haul truck operators were then interviewed about their habits, activities, and common practices. The company's operating procedures for haul trucks were discussed including the requirement to keep the windows and doors closed, reporting of any maintenance problems, and proper radio volume. Additional information was collected including truck engine data (e.g., horsepower, year, make/model), weather or road conditions, planned maintenance activities.

Upon completion of the pre-shift tasks, noise dosimeters were attached at two strategic locations inside and outside of the cabs. In all, there were 44 samples collected over the 13-shift study period. For each sample, two noise dosimeters, one inside and one outside the cab, measured noise (dBA TWA₈) using the MSHA PEL exposure criteria during the full shift. The dosimeter placed outside the cab was used to check for excessive engine sound levels. It was also used to examine the difference in sound levels between inside and outside the cab. In addition, operator activities were monitored and noted throughout the shift. At the end of the shift, the noise dosimeters were recovered and the data downloaded. Finally, a second interview of the haul truck operator was conducted to determine driver activities and other potential co-variables, discuss maintenance issues, and to receive feedback or concerns about the noise study.

Instrumentation and Data Collection

Worker noise exposures were monitored using Quest Q-400 Noise Dosimeters. This instrument is preferred over a sound level meter when the noise levels must be measured over a lengthy period and vary due to intermittent nature. Most dosimeters available today provide outputs in dose or TWA₈ using various exchange rates (e.g., 5 dB), response rates (fast or slow), 8-hr criterion levels, and sound measurement ranges.

Noise dosimeters are typically used to measure personal noise exposures of employees, but can also be used to measure noise exposures as area samples where the dosimeter stays in a stationary location. The dosimeters used in this study measured and stored the sound levels during a time period and computed the readout as a percent dose. The equation below was used to convert the MSHA PEL dose percent to TWA₈ SPL.

$$\text{TWA}_8 \text{ SPL (dBA)} = 16.6 \times \log_{10} (\text{Dose \%}/100) + 90$$

Prior to the shift start, the noise dosimeters were calibrated and set to monitor an MSHA PEL of 100% or a TWA_8 of 90 dB Threshold, 5 dB Exchange Rate, a Slow Response, and a 140 dB Upper Limit. The dosimeter microphone inside the cab was placed as close to the operator's right ear as possible. As shown in Figure 6, the microphone was placed 1.0 – 1.5 feet to the right of the operator next to the engine-side window. Actions were taken to ensure the dosimeters or microphones did not touch the window and produce structure-borne noise.



Figure 6. Dosimeter inside cab.



Figure 7. Dosimeter outside cab.

Outside dosimeters were attached to the frame above the operator's door as shown in Figure 7, except for one occasion where it was raining heavily. On this day, dosimeters were attached to the frame on the opposite side of the cab, and were directly exposed to engine noise. Measures were again taken to protect the dosimeters and microphones from damage and vibration against the cab frame.

Results

A histogram of the TWA_8 SPLs for all of the measurements inside the cab is shown in Figure 8. The shape of the histogram suggests that the data may not be normally distributed, but perhaps a larger sample size would lead to a more normal or log-normal sample distribution. The descriptive statistics for all the sample measurements are as follows: sample mean, 75.1; median, 81.3; standard deviation, 15.4; and 95% confidence intervals of the mean, 70.5 (lower limit) and 79.8 (upper limit).

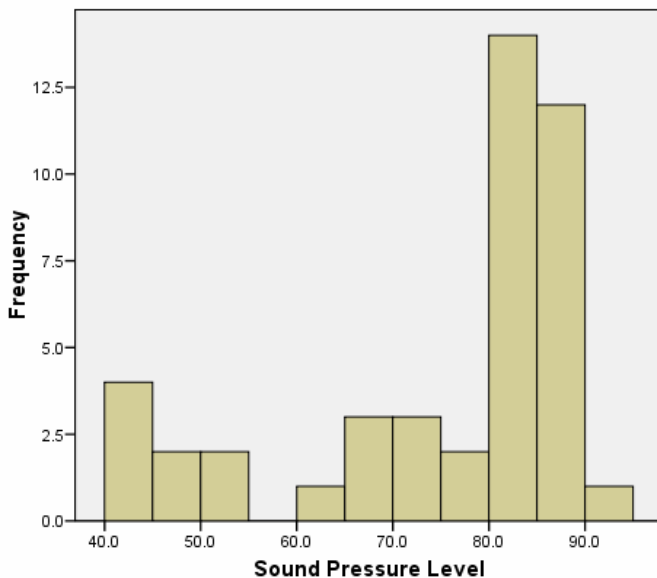


Figure 8. Histogram of the TWA_8 SPL sample data.

There was one extreme outlier (97.7 dBA) in the sample measurements which was not used in the data analysis. When compared to the highest measurement from the study data (90.1 dBA),

the sound energy from the outlier was as much as four times greater. This reading was so high that it was improbable that the haul truck driver could have operated for a full shift without reporting discomfort from excessive cab noise levels. Therefore, this sample measurement is extremely unlikely. In retrospect, it was found that the high reading probably resulted from the microphone beating against the window or cab frame.

Figure 9, Sound Levels of Study Samples Inside Cab, graphically represents the data as the TWA_8 SPLs for each sample collected inside the cab for each cab type. The black data points represent samples where the haul truck drivers had unnecessary intervals of open doors and windows. Figure 9 also shows the limits for the PEL (TWA_8 90 dBA) displayed in red color. Only 1 out of the 44 sample measurements were above the MSHA PEL. However, 14 out of 44 (32%) did exceed levels of TWA_8 85 dBA which may be considered hazardous. Furthermore, Figure 9 shows that the new-style cab samples were fairly spread out, but only one sample came near to exceeding the MSHA PEL. In contrast, the measurements for the old-style cabs and retrofitted cabs were spread out only over the upper range (right side) of the graph which contained the higher noise level samples. Table 1 displays the descriptive statistics of the TWA_8 SPLs for each of the three cab styles including the mean, median, standard deviation, and 95% confidence interval of the mean.

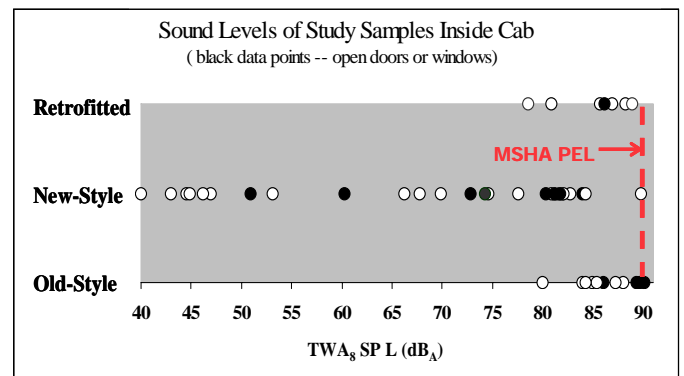


Figure 9. Sound levels measurements for each cab type.

Table 1. Descriptive statistics for three cab styles.

	Retrofitted TWA_8 SPL (dB)	New style TWA_8 SPL (dB)	Old style TWA_8 SPL (dB)
Mean	85.1	67.7	86.3
Medium	86.1	82.1	86.0
Standard deviation	3.86	16.2	3.0
95% CI			
Lower	81.5	61.2	84.3
Upper	88.7	74.2	88.3

Figure 10 depicts a box plot of the data showing the median, and upper and lower quartiles for each cab type. It appears that the median values of the MSHA PEL noise exposure for the old-style and retrofitted cabs are very similar, but both differ from the new-style cab median. The median value of the new cab style is much lower than the other two cab styles.

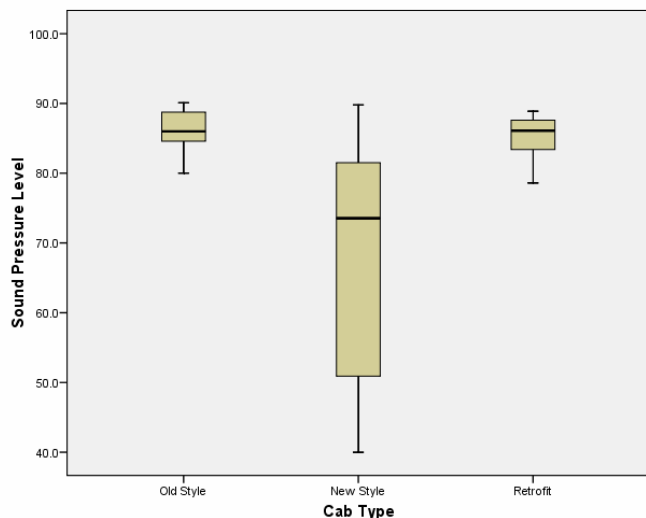


Figure 10. Box Plot of TWA₈ SPL for the 3 cab styles.

Because of questions regarding the underlying distribution of the sample data, the parametric ANOVA and non-parametric Kruskal-Wallis tests were performed to determine if there were significant differences in the TWA₈ SPLs inside the cab between the 3 cab styles. ANOVA tests were performed with Tukey post hoc comparisons. Although significance is usually set at alpha equal to .05, these tests were done to see if the p-values approached significance (p-value <.05). Table 2 displays the results from all of these tests.

Table 2. Comparison statistics for three cab styles.

Parametric test	F statistic	P-value
ANOVA	10.7	0.0001
Tukey Post Hoc Test (multiple comparisons)		
New-style vs. Retrofitted		0.007
Old-Style vs. Retrofitted		0.987
New-style vs. Old-Style		0.001
Non-Parametric Test	Chi-square statistic	P-value
Kruskal-Wallis	20.9	0.0001

The null hypothesis for an ANOVA test is typically that there is no difference or effect among groups and a p-value close to zero signals that the null hypothesis is rejected. The ANOVA test of the sample data achieved a p-value of 0.0001 which achieves significance (p-value<.05), suggesting that the null hypothesis should be rejected and that there is a difference in at least one of the three cab styles. As seen on Table 2, the Kruskal-Wallis test on the data achieved a p-value of 0.0001 which was the same as the ANOVA test. Results from the Tukey post hoc multiple comparison test on this data show that a p-value of 0.001 was achieved between the old-style and new-style cabs and a p-value of .007 was achieved between the retrofitted and new-style cabs. These two comparison tests indicate a significant difference between the groups for each test. The comparison for old-style and retrofitted cabs did not show significance (p-value = .978) that there was a difference between the groups.

Unnecessary open doors or windows was observed in 13 out of the 44 samples (30%). These observations were seen in 3 out of the 4 highest noise levels measured during the study, including the highest measurement of 90.1 dBA. Table 3 shows the mean noise exposure for samples with open doors or windows versus the mean for samples where open doors or windows were not observed for each cab style. The increase in noise was 8.5 dBA for the new-style cabs, 4.0 dBA for the old-style cabs, and 1.2 dBA for the retrofitted cabs. This data

shows a significant increase in noise for the new-style and old-style cabs. A broken air conditioning unit was the reason for the higher noise measurement in only one of the samples. Operators provided the following additional reasons why they opened their doors or windows: fogged interior windows, tobacco use, the preference for outside air, and the need to hear the horn/signal from the front-end loader.

Table 3. Mean SPL for open vs. closed doors and windows for each cab style.

	Doors and windows	
	Open (dBA)	Closed (dBA)
New-Style Cabs	73.6 (n=8)	65.1 (n=18)
Old-Style Cabs	88.8 (n=4)	84.8 (n=7)
Retrofitted Cabs*	86.1 (n=1)	84.9 (n=6)

Good road conditions were noted throughout the study and normal weather conditions were observed. Some cab deterioration was visible in the old-style and retrofitted cabs, but little in the new-style cabs. Aside from wear and tear due to normal use, the seals, gaskets, and latches were in fair to good condition. Finally, no excessive engine noise levels were found in any of the samples.

Discussion and Conclusions

The results from this study show that 43 out of 44 (98%) measurements inside cabs were below the MSHA PEL, regardless of open doors and windows, the cab maintenance condition, or the cab style. However, noise reduction measures should be made to reduce noise even further to prevent NIHL.

Multiple comparison tests and descriptive data both show that there is a significant difference between the old-style and new-style cabs and the retrofitted and new-style cabs. Therefore, efforts to control noise inside the new-style cabs have been effective and mine management should continue their efforts to purchase haul trucks that have cabs equipped with these state-of-the-art noise-reduction features. Fortunately, as mines begin to replace old haul trucks with new haul trucks that have the new-style cabs, noise overexposures should become infrequent as long as operators keep the doors and windows closed.

Finally, both multiple comparison tests and descriptive statistics suggest there is no difference between the old-style and retrofitted cab styles, highlighting the difficulty of designing and implementing retrofit noise controls. The lack of significant benefit from the retrofitted cabs in the study's limited sample does not entirely rule out retrofits as a useful noise control strategy. Instead, some potential shortcomings were identified that, if corrected, could lead to more effective retrofits. Improved interventions to reduce door and window vibration could serve to further reduce these noise levels. Also, noise treatment of the cab floor could improve noise reduction significantly because of the relative proximity of the cab floor to the engine noise sources. Finally, treating the outside of the cab (engine side of the firewall and under the hood) with sound absorbing materials should also help to reduce the amount of noise inside the cab.

Open doors and windows will increase the noise levels inside the cab and measures should be taken to encourage operators not to disable these protective cab features. Improved education and training of operators is needed regarding noise source awareness and the health consequences of tobacco use and noise overexposures. Furthermore, enforcement of noise policies should be strengthened. Technical interventions, such as alarms or lighted warnings that alert the operator when a window is open (similar to seat belt dash warnings), may heighten awareness that operators are at higher risk of a noise overexposure and encourage them to take appropriate action.

Two factors add a degree of uncertainty in this study. The first is the fairly small sample size for old-style and retrofitted cabs and the second is that the research was conducted at only 5 mines sites. Further studies of additional haul truck cabs (at a variety of mine sites) would enhance the certainty of the study results. In addition, the observations of operator activities could only be made while a haul truck was visible while on the surface and the activities that occurred underground could not be monitored. The collection of data on

underground activities depended on the reliability of the information provided by the haul truck operator and could be affected by self-report bias and errors. More direct observation techniques could help alleviate this problem.

Disclaimer

The findings and conclusions in this report have not been formally disseminated by the National Institute for Occupational Safety and Health and should not be construed to represent any agency determination or policy.

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